FURROW IRRIGATION EROSION EFFECTS ON CROP PRODUCTION

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Furrow erosion and sediment deposition redistributes topsoil within fields. Both of these processes are directly proportional to the energy of the furrow irrigation stream. This stream must be large enough at the application point to provide sufficient water for infiltration along the entire furrow length to meet the purposes of irrigation. Where slopes exceed about 0.7% on many silt loam soils, the flow velocity combined with the stream size at the upper ends of fields has sufficient energy to erode soil (Berg and Carter, 1980). As the furrow stream size decreases from infiltration along the furrow, the energy to erode and transport soil also decreases. At some point along the furrow the stream energy reaches a level where it no longer erodes soil. Then, further down slope, the energy reaches a level where the stream will no longer carry the accumulated sediment from upstream erosion. At that point sedimentation begins and continues downslope. The quantity of eroded soil actually leaving the field through the furrow depends upon the sediment load in the furrow stream at the entry point into the drain ditch at the lower end of the field and the duration of the flow at that point.

Furrow irrigation erosion and the resulting soil loss is generally greatest on the upper portion of fields (Berg and Carter, 1980; Carter and Berg, 1983; Mech and Smith, 1967) where the furrow stream size is largest and the energy to erode is greatest. Erosion is also often severe along portions of the furrow where the slope is greater than along other portions of the run length (Carter and Berg, 1983). Where furrow erosion occurs irrigation after irrigation, the topsoil is gradually eroded away. The impact of this topsoil loss on crop production is of concern. This paper reports results from a study to quantify crop yield losses resulting from furrow irrigation erosion.

SOILS OF THE STUDY AREA

The soils of the study area are Portneuf silt loam (Durixerollic Calciorthid) and similar silt loams, with a lime and silica cemented hardpan (caliche) that begins 0.3 to 0.45 m below the surface and varies in thickness from 0.2 to 0.45 m. The topsoil is pale brown (10YR 6/3) silt loam with a silt content ranging from 62 to 67%. The hardpan is white (10YR 8/2) silt loam, strongly cemented, with a silt content ranging from 65 to 75%, and a $CaCO_3$ content ranging from 25 to 35%. The soil below the hardpan is light gray (10YR 7/2) silt loam with a silt content generally greater than 70%, and this soil has little structure.

Areas where the hardpan soil or the soil below the hardpan has been brought to the surface by cultivation, or exposed by erosion and cultivation or land leveling, appear whitish in color in contrast to the pale brown topsoil. The upper ends of many fields in the study area are whitish because furrow irrigation erosion has reduced the topsoil depth sufficiently that plowing has fractured the white caliche layer and brought part of it to the surface.

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In: Proc. Natl. Symp. on Erosion and Soil Productivity, Dec. 10-11, 1984, New Orleans, LA.

Results of a survey we made of fields in the study area indicated that 70 to 75% of the fields exhibited whitish upper ends. The average portion of whitish soil on 14 farmer operated fields studied was 30%. Multiplying that value by the 70% of the fields with whitish areas gives a value of 21% of the area as eroded sufficiently that topsoil has been reduced from the original average of 0.38 m deep to a significantly shallower depth through which plows have fractured and brought portions of the caliche layer to the soil surface. We observed many fields where topsoil loss has exceeded 0.3 m immediately below the head ditch. The area has been irrigated for 78 years, and rough estimates of the yearly erosion loss can be made from the depth of soil eroded away from the upper ends of fields.

The soils of the study area represent more than a million hectares of irrigated land, and much more nonirrigated land in Idaho. Large areas of similar silt loam soils are present in Oregon and Washington and some other Western States. Not all of these similar soils have caliche layers.

STUDY METHODS

Two approaches were applied during the 1982, 1983, and 1984 growing season to evaluate the impact of furrow irrigation erosion on crop production. One approach involved 17 farmer operated fields. All of these fields had been furrow irrigated for 75 to 78 years except one which had been converted to sprinkler irrigation after approximately 65 years of furrow irrigation. Topsoil depth was measured using soil probes or augers along four transects parallel to the head ditch. These transects were located by measuring the distance that the whitish soil extended downslope from the head ditch where a transition zone was clearly evident between the whitish soil and normal topsoil. This transition zone represented where the plow depth was the same as the topsoil depth. The first transect was one half the distance between the head ditch and the transition zone. The second was at the transition zone, the third was about one-third the distance between the transition zone and the lower end of the field, and the fourth was approximately 30 m from the lower end of the field.

Crop yields were measured along these same transects for relating crop yield to topsoil depth. Over two seasons, data were obtained from six wheat (<u>Triticum aestivum</u> L.), seven dry bean (<u>Phaseolus ssp</u>.), two alfalfa (<u>Medicago sativa</u> L.), one sugarbeet (<u>Beta vulgaris</u> L.), and one Norgold Russet potato (<u>Solanum tuberosum</u> L.) fields.

The other approach involved field plots where the topsoil depth increased successively from 0.10 to 0.65 m. This plot area was formed by removing top soil from portions of the site and adding it to other portions. Six crops were grown on 24 successively deeper topsoil plots between the two extremes. The crops included wheat, dry beans, alfalfa, sugarbeets, barley (<u>Hardeum vulgare</u> L.) and sweet corn (<u>Zea mays</u> L.) The plots were fertilized with nitrogen, phosphorus and zinc to assure adequate levels of all plant nutrients. Some potassium treatments were applied to determine if potassium might be deficient where most of the topsoil was removed. Water was applied by furrow irrigation at a frequency sufficient to assure that water stress in the growing crops was not a growth limiting factor. These plots were cropped the 1983 and 1984 seasons. Plot areas were rotated so that the same crop was not grown on the same plots for two successive years except for alfalfa.

Crop yields were measured by harvesting specific lengths of rows for row crops and clipping specific areas for cereals and alfalfa. Sufficient replicates were harvested for statistical evaluation. These statistical evaluations included analyses of variance for potatoes where only one site was studied. Both linear and curvilinear regression analyses were applied to evaluate topsoil depth-yield relationships for other crops.

Reducing topsoil depth from the original 0.38 m decreased yields of all crops studied. Wheat and sweet corn yields were decreased most and sugarbeet yields were decreased the least. Alfalfa and barley yields followed similar patterns with reduced topsoil depth, and the response of dry beans was cultivar dependent. Some bean cultivars were affected similar to sweet corn and wheat, while other cultivars were not significantly affected.

Relative yields of each crop at each topsoil depth were calculated based upon the maximum yield measured along a transect on farmers' fields or the maximum yielding plot in the plot study. Yields along other transects or on other plots were expressed as percent of these maximum yields. Linear regression analyses were made on the yield data for topsoil depth up to and including the original 0.38 m, and a separate analysis was made for topsoil depths greater than 0.38 m. The purpose of this type of analysis was to obtain an estimate of yield loss per unit of topsoil depth loss from erosion and the yield increase per unit of topsoil depth increase from deposition.

The percent maximum yield vs. topsoil depth relationship for wheat indicated that for each 0.01 m decrease in topsoil depth below the original 0.38 m, wheat yield was decreased 1.55% (Fig. 1). Increasing topsoil depth above original depth had no significant effect on wheat yield based upon this linear regression approach. The data in Fig. 1 include 1983 and 1984 plot yields and yields measured along transects in farmers' fields. Seasonal effects were evident on the research plots. Plotting the 1983 and 1984 data separately gave slightly different slopes. These lines are not shown, but the data points provide evidence of the slope differences.

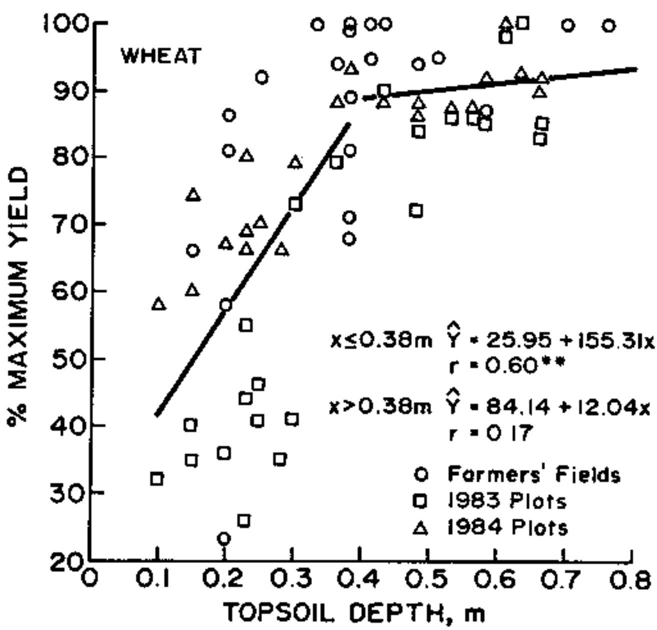

Fig. 1 The Effect of Topsoil Depth on Wheat Yield

The response of sweet corn yields to changes in topsoil depth was similar to that for wheat (Fig. 2). Sweet corn data were taken from the plot study only. Sweet corn yields were lower in 1984 than in 1983, and there was some evidence of seasonal effect, as was noted with wheat. As with wheat, increasing the topsoil depth above 0.38 m had no significant effect upon sweet corn yield.

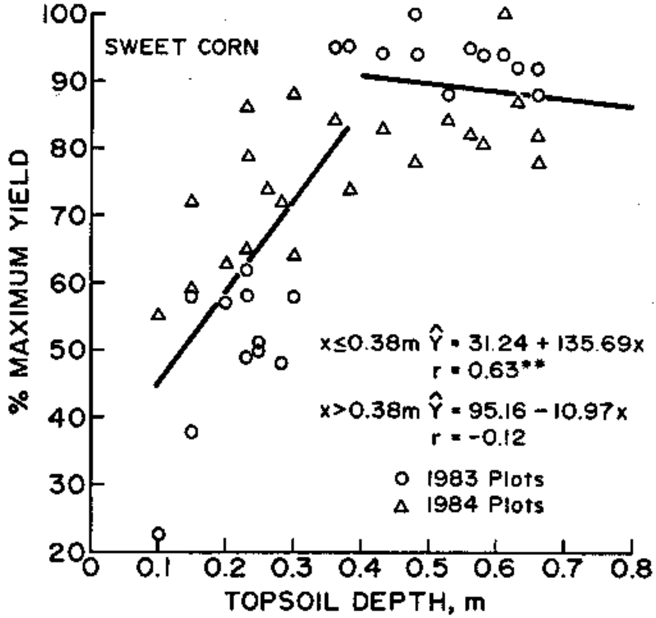

Fig. 2 The Effect of Topsoil Depth on Sweet Corn Yield

Many cultivars of dry beans are produced in the study area. We grew Royal Red kidney beans on the experimental plots in 1983, and they responded similarly to sweet corn and wheat to changes in topsoil depth. In contrast, the yield of red chili beans grown in 1984 was not significantly affected by topsoil depth. Results for the 1983 plot and farmer field data are shown in Fig. 3. Several different bean cultivars were grown on farmers' fields, and therefore, considerable variability is evident in the results. Dry bean yields were significantly increased by increasing topsoil depth above 0.38 m. The yield increase per unit increase in topsoil depth was less than the yield decrease per unit decrease in topsoil depth. Both relationships were statistically significant.

Barley and alfalfa yields were affected almost identically by changes in topsoil depth. The relationships for both crops are shown in Fig. 4. Because of the numerous data points for alfalfa resulting from three cuttings per season, the data points are not shown on the figure. The relatively low correlation coefficient for alfalfa indicates the wide variability in alfalfa yields at various topsoil depths. Even with this high variability, the relationship was significant at the 1% level for topsoil depths of 0.38 m and less.

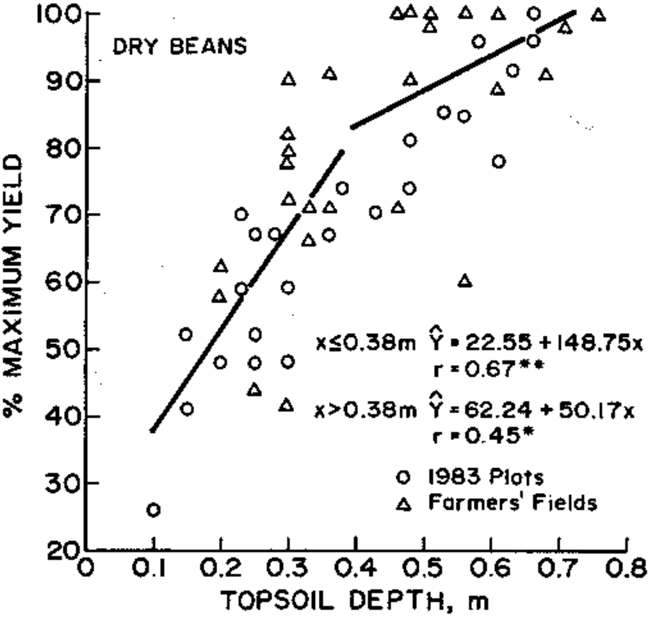

Fig. 3 The Effect of Topsoil Depth on Dry Bean Yield

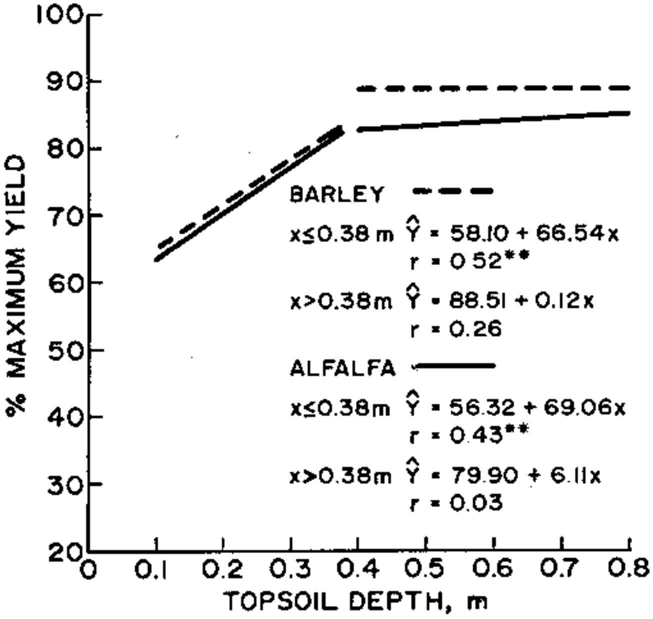

Fig. 4 The Effect of Topsoil Depth on Alfalfa and Barley Yields

The relationship for barley had less variability than for alfalfa. Neither of these crops were affected as severely by loss of topsoil as were wheat, sweet corn, and beans. Increasing topsoil depth did not significantly affect yield of these two crops.

High yields of sugarbeets were measured on all 1983 plots and on the one farmer field studied. The relationship between yield and topsoil depth was significant, but the effect of topsoil loss is less for sugarbeets than for the other crops studied (Fig. 5).

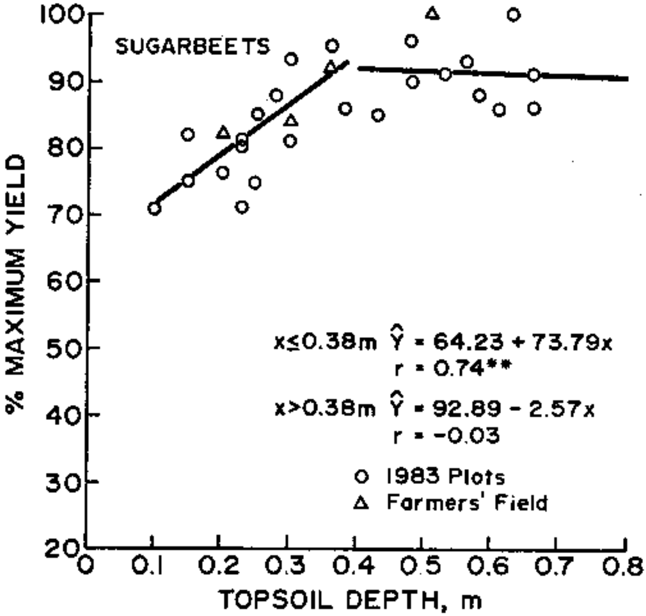

Fig. 5 The Effect of Topsoil Depth on Sugarbeet Yield

Potato yield and grade both decreased as topsoil depth decreased (Table 1).

Table 1. Potato yield and grade at different topsoil depth

Topsoil Depth	Yield	% No. 1 Grade Baker >283g	113-283g	Total	No.2	Cull
m	Mg/ha	%				
Whitish	45	11	53	64	11	25
0.38	51*	25	47	72	8	20
0.56	62*	12	60	72	12	16

*LSD (0.05) = 3.59 Mg/ha

Only one farmer operated field was sampled, and the data were evaluated by analyses of variance. Yield along three transects are shown. Total yield continued to increase up to a topsoil depth of 0.56 m indicating that topsoil depth increases from sediment deposition benefitted potato yields. The percent No. 1 grade was greater where the topsoil was 0.38 m deep or deeper than on the whitish soil area.

Curvilinear regression analyses were completed for all of the crops except potatoes for the 1983 and 1984 data. Significant relationships were obtained for all crops when using the equation $y = a + b \ln x$, where y is yield and x is topsoil depth. Yields for all depths were included in the same analyses instead of separating yields for depths of 0.38 m and less and those greater than 0.38 m. The equations and R^2 values are presented (Table 2) but the relationships are not illustrated. All relationships were statistically significant. These relationships tended to indicate a greater yield increase with increasing topsoil depth than was actually the case. The scatter of data points was greater along the upper portions of the curves. Therefore, we concluded that the linear relationships give a better representation of the true effects of topsoil depth increases on crop yield. Additional curvilinear regression analyses will be made using different equations and additional data from the next season. Ultimately, a curvilinear relationship over the entire topsoil depth range would be most usable for making predictions.

Table 2. Curvilinear regression equations and correlation coefficients relating crop yield to topsoil depth for 1982 and 1983 data. All relationships were significant at the 0.001 probability level.

Crop	Equation	R^2
Wheat	$\hat{Y} = -57.17 + 37.23 \ln X$	.518
Sweet Corn	$\hat{Y} = -65.66 + 39.26 \ln X$	.799
Dry Beans	$\hat{Y} = -46.98 + 33.68 \ln X$	.685
Barley	$\hat{Y} = -2.90 + 23.59 \ln X$	.765
Alfalfa	$\hat{Y} = 7.94 + 19.28 \ln X$	.389
Sugarbeets	$\hat{Y} = 45.25 + 11.68 \ln X$	.529

DISCUSSION

Results of our investigations clearly show that topsoil loss from furrow irrigation erosion decreases crop yields in the study area. Today, significantly lower yields of most crops are being harvested on at least 20% of the farmed area. There is also evidence that yields of some crops may be greater where deposition of soil eroded from upslope portions of the furrow has increased topsoil depth. However, yield increases per unit of topsoil depth increase are small where they occur, whereas yield decreases per unit of topsoil depth decrease are larger and are additive to rather high percentages in yield reduction as erosion removes more topsoil year after year.

The factors causing the yield decreases where topsoil depth is decreased and where subsoils have been brought to the surface have not been identified. Our plot studies and farmer management have appeared to have ruled out both plant nutrient deficiencies and water deficits by assuring adequate levels of both for growing crops. At present, we do not know how to restore production on these areas where it has been reduced. Perhaps returning topsoil from deposition areas to eroded areas will restore yield potential, but this needs to be verified. Even if this approach restored yield potential, the cost may be prohibitive. Furthermore, there are many fields in the study area where much of the eroded soil has been carried off the field into drainage streams. This lost topsoil cannot be returned.

The fields in the study area have been furrow irrigated only 75 to 78 years, and erosion has seriously reduced yield on more than 20% of the area. Farmers in the area are confronted with a serious problem in the future. It is difficult to predict how rapidly the yield reduced area will expand, but it is important that every practice available be applied to limit additional erosion.

Results of these investigations apply to over a million hectares of irrigated land in Idaho, and likely apply to large areas of similar soils in several other western states. Additional research is needed to determine if similar relationships between yield and topsoil depth exist on soils without caliche layers. We are planning research of this kind for future growing seasons. Also needed is research on possible methods to restore productivity of eroded areas. We are investigating the feasibility of using earth-moving equipment to move topsoil from deposition areas to eroded areas to determine if such a practice will restore the productivity of the eroded areas.

The economic impact of furrow irrigation erosion is serious. More than 20% of the land in our study area has a yield reduction from about 10% to as much as 70%. If we assume an average yield reduction of 40% over the eroded area, we find that the productivity of the entire area has been reduced nearly 10% by the erosion that has occurred over the past 75 to 80 years, compared to the potential production had there been no erosion. A 10% decrease in gross income without any decrease in expenses can have a serious impact on farmers' operations. Furthermore, until we find a method to restore that productivity, and without erosion control, the reduced income not only occurs every year, but it becomes greater as erosion reduces yield on more land and further decreases yield on already eroded areas. These estimates are conservative, because there are areas where the topsoil depth has been reduced by erosion, but not yet sufficiently to expose the white caliche layer. These areas also have reduced yields, and were not included in our surveys.

All available erosion control technology for furrow irrigated land should be applied to reduce further erosion and topsoil loss. This is important from the economic standpoint of present operators and to maintain productivity of the land for future generations.

SUMMARY

Furrow erosion and sediment deposition redistributes topsoil within irrigated fields. Where slopes exceed about 0.7% on many silt loam soils, the upper ends of fields have been severely eroded. Studies conducted on Portneuf silt loam and similar soils with a white, caliche and silica cemented layer originally beginning at a depth of about 0.38 m, showed that erosion has been sufficient to expose the white, caliche layer on 70 to 75% of the fields over about 78 irrigation seasons. The area now visually exhibiting whitish color as a result of erosion and plowing to expose or bring to the surface, white, caliche, represents more than 21% of the farmed area.

Yields of all crops grown in the study area are severely reduced on those portions of the fields that are whitish in color as a result of erosion.

Significant linear relationships between crop yield and topsoil depth were developed for wheat, barley, sweet corn, dry beans, alfalfa, and sugar beets, and a significant yield reduction was measured for potatoes. Wheat, dry beans, and sweet corn yields were reduced most, alfalfa and barley yields were reduced somewhat less, and sugar beet yields were least affected by topsoil loss from erosion.

Results showed that furrow irrigation erosion has significantly reduced crop yields on more than 20% of the cultivated land in the study area. These results indicate that crop production has been reduced about 10% by erosion that has occurred over the past 75 to 80 years, compared to the potential production had there been no erosion. A 10% decrease in gross income without any decrease in expenses can have a serious economic impact on farmers' operations.

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